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Carbon footprint and cost analysis of a bicycle lane in a municipality

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ABSTRACT

BACKGROUND AND OBJECTIVES: Cycling has been widely promoted as an alternative mode of transport to help the reduction of environmental impact and improve users' health. Promoting cycling will help enhance the "Green City" initiative in Thailand. While several studies have addressed social issues of cyclists, the environmental impacts and economic viability of cycling infrastructure are yet unknown. Quantifying its environmental impact and the costing aspect are essential to prove that cycling would positively affect a city. This study compares the expected environmental and economic impacts before and after constructing a bicycle lane in Mahasarakham, Thailand.

METHODS: This study uses life cycle assessment and life cycle costing to assess a bicycle lane's environmental and economic viability. Life cycle assessment and life cycle costing are tools used to analyze environmental impact and cost during the life cycle of a product or service. The scope of this study covers the processing of raw material acquisition, transportation, construction, use, and disposal. The functional unit set for this study is the use of a bicycle lane for one year. The environmental impact examined is greenhouse gas emissions along the product's life cycle (the so-called "carbon footprint").

FINDINGS: According to the results, approximately 0.2 million tons of carbon dioxide equivalent of carbon footprint could have been reduced in 2020 had a bicycle lane been installed. The use phase plays the leading role in reducing carbon footprint. The reduction in environmental impacts is due to reduced fuel consumption by cars and motorcycles when bicycles are used. Even though a low rate (26%) of road users, who participated in this research, were willing to ride bikes had a bicycle lane been provided, a considerable amount of environmental impact could still have been reduced.

CONCLUSION: The carbon footprint expected to be reduced in a year is valued at about 4.7 million baht of carbon credit. In comparison, the life cycle cost of bicycle lanes for one year is approximately 3.7 million baht. Furthermore, it is anticipated that had a bicycle lane been installed since 2015, the city would have reduced overall carbon footprint emissions by more than 1.15 million tons of carbon dioxide equivalent by 2020. Therefore, the results of environmental impact and cost assessment from this study are helpful for urban environmental management.

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INTRODUCTION

Cycling has been endorsed worldwide as an alternative mode of transportation to promote the transition to a green society. Promoting bicycles has been one of Thailand's "Green City" action plan measures for 2017–2027 (Kongboon *et al.*, 2021). Mahasarakham is located in the middle of the northeastern region of Thailand and is a city that has the potential to operate a bicycle lane system. The traffic in this city is moderate, and there are several educational institutions. This situation is an excellent opportunity to promote healthy transportation means to the youth. In 2020, Mahasarakham municipality officially hosted about fifty-five thousand inhabitants (Mahasarakham Municipality, 2020). Chaowarat *et al.* (2016) studied public policy to promote a bicycle lane in Mahasarakham city. They identified different factors to address before endorsing cycling in the city. Despite the feasibility of installing a bicycle lane system based on policy and attitudes of potential bicycle lane users, the environmental aspects and economic viability of the system in Mahasarakham had not yet been studied. Mitigating climate change is the dire need of the hour. Greenhouse gas (GHG) emissions from different human activities are the primary cause of this global environmental issue. Transportation is one of the key sectors contributing to GHG in Thailand. More importantly, the country pledged in its 'Nationally Appropriate Mitigation Actions' in December 2014 to reduce its GHG emissions in the energy and transportation sectors by 7-20% on a business-as-usual basis by the year 2020 (TGGMO, 2014). More recently, Thailand pledged in COP 26 that the nation aims to reach carbon neutrality by 2050 and net-zero GHG emissions by or before 2065 (MFA, 2021). This commitment emphasizes the urgent need for the country to reduce GHGs effectively. The expected GHG emissions before and after the construction of a bicycle lane must be quantified to prove that a bicycle lane would effectively reduce GHGs and promote the "Green city" initiative. Literature reveals that much emphasis has been placed on researching cycling. However, although it has been widely researched in Western countries it has seldom been studied in Thailand. Recent research has been targeted towards health, safety, and cyclist behavioral issues. For example, Andersen *et al.* (2018) examined cycling and cycling-related injury trends in four of Denmark's largest cities to measure if changes in cycling trips and injuries were linked. Bourne *et al.* (2018) evaluated the health benefits of electrically assisted bicycles in the United Kingdom. Boufous *et al.* (2018) examined the effects of environmental factors on riders' speed in Sydney, Australia. Huemer (2018) identified factors making people ride bikes under the influence of alcohol in Germany and then designed safety measures. Mandic *et al.* (2018) examined the effects of short-term cycling training on children's cycling knowledge, confidence, and behaviors in Dunedin, New Zealand. Shrestha *et al.* (2020) assessed cyclists' exposure to particulate matters in Perth, Western Australia. Castells-Graells *et al.* (2020) studied factors affecting the risk and discomfort of cyclists in Zurich, Switzerland. In Thailand, a few studies have found factors influencing cycling attitudes to help promote cycling in cities. Singsaktrakul and Muneenam (2019) examined potential features to support tourists for cycling in Songkhla province and Ratanaburi *et al.* (2021) examined the impact of stakeholder involvement on the quality of a bicycle lane infrastructure in the capital, Bangkok. A summary of aspects considered by different recent studies is presented in Table 1.

As it is shown in Table 1 the recent literature mainly deals with cyclists' issues, and most studies have been conducted in other countries. In Thailand, there have been two recent studies of cycling, both of which examined cyclists' aspects. Although one study also investigated cycling infrastructure, only the quality of a bicycle lane was considered. The environmental and cost factors have not yet been examined. To prove that a bicycle lane provision would positively impact society, ecological and economic changes need to be measured. Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) are tools used to assess the environmental impacts and costs during the life cycle of a product/service (Klöpffer and Grahl, 2014). These tools are well-known to support decision-making as they can help prevent shifting problems from one stage to another in the life cycle of a product/service. This study uses LCA and LCC to examine the life cycle greenhouse gas (GHG) emissions (in other terms, "Carbon footprint") and the costs of a bicycle lane system in a municipality. The carbon footprint accounts for different GHGs which may be emitted, such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), throughout a

Table 1: Summary of examined issues of cycling for different recent studies

Country	Subjects		References
	Cyclist	Infrastructure	
Denmark	Cycling-related injuries	-	Andersen *et al.* (2018)
United Kingdom	Health benefits	-	Bourne *et al.* (2018)
Australia	Factors on speed	-	Boufous *et al.* (2018)
Germany	Behaviors under the influence of alcohol	-	Huemer (2018)
New Zealand	Effects of training on children's cycling skills	-	Mandic *et al.* (2018)
Thailand	Features to support tourists for cycling	-	Singsaktrakul and Muneenam (2019)
Australia	Exposure to particulate matters	-	Shrestha *et al.* (2020)
Switzerland	Risk and discomfort	-	Castells-Graells *et al.* (2020)
Thailand	Stakeholder involvement	Quality of a bicycle lane	Ratanaburi et al. (2021)

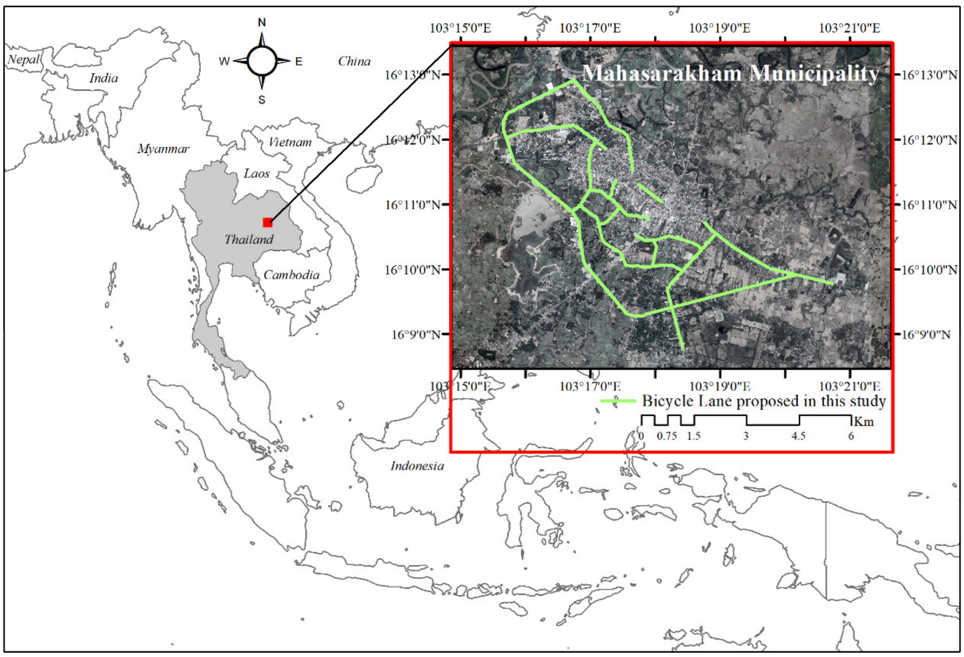

Fig. 1: Geographic location of the study area in Mahasarakham municipality in Thailand

product's life cycle (CSS, 2021). These are sometimes called "life cycle greenhouse gases". The life cycle stages considered for this study include; material acquisition, transportation, construction, use, and disposal. The results are expected to be used as supporting information for policymakers. The study compares the expected carbon footprints before and after installing a bicycle lane system and the cost involved during its life cycle. This study was carried out in Mahasarakham city, Thailand, from 2015 to 2020.

MATERIALS AND METHODS

The main goal of this study is to compare the carbon footprints and costs before and after constructing a bicycle lane in Mahasarakham municipality, Mahasarakham, Thailand. The geographic location of the study area is presented in Fig. 1. Mahasarakham city is located in the middle of the northeastern region of Thailand. This study is based on the bicycle lane construction plan designed by the Faculty of Architecture, Urban Design, and Creative Arts, Mahasarakham University, Thailand. The bicycle lane

network design which covers approximately 32 km is illustrated in Fig. 1.

This study hypothesizes that a bicycle lane provision would help reduce the carbon footprint which could be used to offset the cost of constructing a bicycle lane. The carbon footprint and life cycle cost incurred before and after installing a bicycle lane must be calculated to prove this hypothesis. The tools used to assess the carbon footprints were life cycle assessment and life cycle costing for life cycle costs.

Life cycle assessment

This LCA study was conducted following the framework of ISO 14067: 2018 Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification (IOS, 2018). Following the guidelines, there were four main stages, i.e., goal and scope definition, inventory analysis, life cycle impact assessment and interpretation.

Goal and scope definition

This study aims to determine whether installing a bicycle lane in Mahasarakham city will help reduce life cycle GHG emissions and to quantify those emissions. The analysis compares the expected total GHG emissions before and after installing a bicycle lane in the city. The system boundary of this study covers the processes of; raw material acquisition, transportation, construction, use, and disposal. The functional unit set for this study is the use of a bicycle lane for one year. The assessment covers the year 2015 to 2020.

Life cycle inventory (LCI) analysis

Life cycle inventory (LCI) is defined as the inputs (energy, resources, and materials used) and outputs (emissions) examined in each life cycle stage of the bicycle lane. The aforementioned data was required for the impact assessment. Therefore, the LCI data was calculated considering the functional unit set (using a bicycle lane for one year). The LCI data were obtained from different sources and were computed using spreadsheets. The details of LCI data analysis for each life cycle stage of the bicycle lane are described as follows.

Raw material acquisition

The LCI data for all raw materials used in the life cycle of the bicycle lane studied was obtained from existing databases (TGGMO, 2021a).

Transportation

LCI data for this stage refers to transportation information of raw materials and bicycle lane construction. These data were acquired by interviewing a road construction contractor.

Construction

Since the bicycle lane had not yet been constructed in Mahasarakham, LCI data for this stage were obtained from secondary data such as the bicycle lane construction plan designed by the Faculty of Architecture, Urban Design and Creative Arts, Mahasarakham University, Thailand and Siam Traffic (2021). The main activities included in the plan were road markings on the designed bicycle lane system and construction facilities (road signs and bicycle parking). Note that the construction of facilities is excluded from this study since facilities are long-lived during the use phase. Therefore, their impacts are considered less significant for the functional unit set of this study (use of a bicycle lane for one year).

Use

LCI data for this stage was obtained by comparing LCI data on the use of vehicles on the existing roads before construction with that expected after installing a bicycle lane. The transportation volume data obtained from 1,447 road user surveys were used in this stage to determine whether bicycles would have been preferred had a bicycle lane been installed. The transportation volume assessment was conducted in December 2015. The transportation volume counting was done thrice a day during rush hours between 8.00-9.00 am, 12.00-1.00 pm, and 5.00-6.00 pm on weekdays and weekends. Note that future transportation volumes of future roads were assumed to have transportation volumes similar to that of the existing roads. The average daily transportation volumes were estimated using the parameters suggested in SPU, (2012). Finally, the average yearly transportation volumes were calculated using the average daily transportation volumes (weekdays and weekends), assuming that there are 260 weekdays and 105 days during weekends in a year. The final LCI results of this stage were the LCI data obtained by comparing the transportation volume expected after and before the bicycle lane installation, using Eq. 1.

$$LCI_u = LCI_{ua} - LCI_{ub} \quad (1)$$

Where LCI_u is the LCI data for the use phase of the bicycle lane, LCI_{ua} is the LCI data for the use phase of the road after having a bicycle lane installed, LCI_{ub} is the LCI data for the use phase of the road before having a bicycle lane installed.

If the results are negative, it signifies a reduction in energy consumption, resources, and materials. In addition, a decrease in GHG emissions from the year 2016 to 2020 was estimated using data from the year 2015 and numbers of vehicles registered in Mahasarakham city for different years from the NSO, (2020).

Disposal

LCI data for this stage included energy used and emissions during the removal of the bicycle lane. These data were acquired by interviewing a road construction contractor. In this case, it is a disposal of road markings with a functional life of two years.

Life cycle impact assessment

The life cycle GHG emission (carbon footprint) assessment was calculated by multiplying emissions factors by LCI data obtained from the previous stage, using Eq. 2.

$$CF = LCI_1 EF_1 + LCI_2 EF_2 + \ldots + LCI_k EF_k \quad (2)$$

Where *CF* is the carbon footprint in the unit of $kgCO_2eq$, LCI_i (1, 2, 3 ... k) is the LCI data (unit differs depending on the type of LCI), EF_i (1, 2, 3 ... k) is the emission factors in the unit of kgCO2eq/unit of LCI data. Thus, an emission factor is a constant showing global warming potential for each LCI. The emission factors used in this study were from EPA, (2021) and TGGMO, (2021a).

Interpretation

This stage is to tackle the goal of the LCA study using the impacts analyzed from the previous step. This study aims to determine whether installing a bicycle lane in Mahasarakham city can help reduce the carbon footprints and to quantify them, using Eq. 3.

$$CF_t = CF_a - CF_b \quad (3)$$

CF_t is the total carbon footprint of the bicycle lane, CF_a is the carbon footprint after a bicycle lane construction, CF_b is the carbon footprint before a bicycle lane construction.

If the total carbon footprint is negative, it implies that the bicycle lane positively affects the municipality, and its installation can help reduce the carbon footprint of the city.

Life cycle costing

Life cycle costs were calculated from raw materials, transportation, construction, use, and disposal processes (Klöpffer and Grahl, 2014). The calculation for the life cycle cost in this study is shown in Eq. 4.

$$C_l = C_r + C_t + C_c + C_u + C_d \quad (4)$$

Where C_l is the life cycle cost of the bicycle lane, C_r is the cost of raw materials, C_t is the cost of transportation, C_c is the cost of construction, C_u is the cost of use phase, C_d is the cost of disposal phase.

As mentioned before, a bicycle lane system has not yet been installed in Mahasarakham city, and the costs were obtained from secondary data (Bicycle lane construction plan designed by the Faculty of Architecture, Urban Design and Creative Arts, Mahasarakham University, Thailand and Siam Traffic (2021)). Therefore, all costs were adjusted for 2020 using Consumer Price Indices from BT, (2020). In addition, the value of potential carbon credits obtained from greenhouse gas reduction was calculated using carbon credit prices from TGGMO, (2021b).

RESULTS AND DISCUSSION

Environmental impacts

The difference in expected values of the environmental impacts before and after the installation of the bicycle lane is shown in Fig. 2. These are the total carbon footprint of the bicycle lane (in different life cycle stages) calculated using Eq. 3. Based on the functional unit set for this study (using a bicycle lane for one year), the results presented in Fig. 2 were calculated yearly. This yearly calculation is because the GHGs are not influenced by time during construction and disposal phases. However, GHGs for the use phase of bicycle lane is influenced by the number of registered vehicles, which changes every

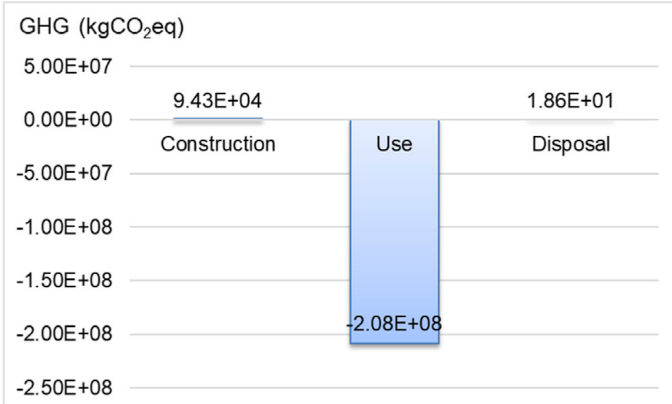

Fig. 2: Total life cycle GHG emissions in different stages for one year

Table 2: Number of vehicles before and after installing a bicycle lane in 1 year

Percentage of frequency for using bicycles	Fraction of vehicle users not using bicycles	Motorcycle Number	Gasoline car Number	Pickup truck Number
Usual		343,649,990	160,554,265	191,156,425
95-100 (97.5)	0.025	429,562	120,416	143,367
72.5-95 (85)	0.15	4,639,275	722,494	1,720,408
50-72.5 (60)	0.4	21,993,599	8,991,039	18,351,017
0-49 (25)	0.75	64,434,373	30,103,925	35,841,830
Never (0)	1	154,642,496	88,304,846	80,285,699
Vehicles remaining on the road		246,139,305	128,242,719	136,342,320
Vehicles reduced after installing the bicycle lane		97,510,685	32,311,546	54,814,105

year. From this stance, the year 2020 is presented in Fig. 2 as it provides the most recent data available from NSO (2020). The total GHGs of a bicycle lane from 2015 to 2020 are presented later in Fig. 4.

The negative results signify that the installation of a bicycle lane can help reduce GHG emissions. In 2020, the amount of GHGs decreased by around 0.2 million tons of carbon dioxide equivalent, influenced by the decrease in the number of vehicles on the road. This decrease in cars/motorcycles will help save fossil fuels, limit burning emissions, and reduce carbon footprint. The primary process which plays an essential role in reducing the impacts is the use phase which accounts for nearly 100 % of the total reduced effects. A similar reduction during the use phase was found by Mrkajic *et al.* (2015), where the installation of a bicycle lane system led to GHG reduction in Novi Sad city, Serbia. In other road infrastructure LCA studies, such as asphalt pavements (Barbieri *et al.*, 2021), it was also found that the use phase is highly significant in reducing emissions. Another LCA study on asphalt pavements by Araújo *et al*. (2014), found that carbon footprint reduction in the use phase of asphalt pavements was due to the decrease in fuel consumption and exhaust emissions from vehicles on the roads. Other minor sources contributing to the carbon footprint of the bicycle lane were GHG emissions from raw materials acquisition and pollutions emitted during the construction and disposal phases. The willingness of road users to opt for bicycles had a bicycle lane been provided is a critical factor in helping reduce the environmental impacts. The difference in the number of vehicles before and expected after installation of a bicycle lane in 2015 is shown in Table 2. These results were calculated using transportation volumes and the percentage of road users willing to use bicycles if the bicycle lane was provided. Overall, the number of vehicles was expected to decrease after installing a bicycle lane by approximately 26% of the usual number. Motorcycles occupy a significant portion (about 53%) amongst the number of vehicles reduced.

Fig. 3 presents the potential GHG reduction from different types of vehicles in additional years during

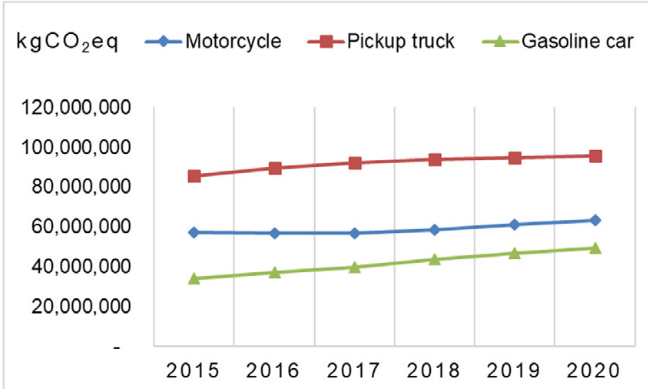

Fig. 3: Carbon footprint reduction by different types of vehicles in the use phase of a bicycle lane

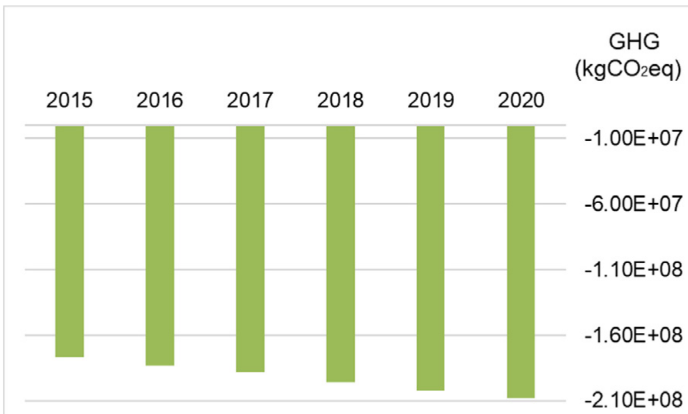

Fig. 4: Total carbon footprint of a bicycle lane for different years

the use phase of the bicycle lane. It is seen that the amount of GHG reduction by pickup trucks is the highest among other types of vehicles. Compared to other vehicles, the expected number of motorcycles reduced after installing the bicycle lane was considerably high (Table 2). Fortunately, since the emission factor for motorcycles is lower than other vehicles, this results in a lower carbon footprint than that of pickup trucks. Another reason that pickup trucks play a dominant role in reducing the carbon footprint is because they use diesel fuel, whereas motorcycles and gasoline cars are fueled by gasoline. Therefore, the emission factor for diesel-fueled vehicles is higher than those using gasoline (EPA, 2021), leading to a higher carbon footprint value. A study by Chang and Huang, (2021) also found that the carbon footprint of diesel-fueled buses is higher than buses using other fuels. On the other hand, gasoline cars showed the least GHG emission reduction since they have the lowest expected reduction after the bicycle lane installation (Table 2). When considering the carbon footprint reduction across the years examined, all vehicles showed an increasing trend. This increase was due to the increase in the number of vehicles registered in Mahasarakham city every year (NSO, 2020).

Fig. 4 shows the total life cycle GHG emissions of a bicycle lane used from 2015 to 2020. These results include the carbon footprints of all life cycle stages considered; construction, use, and disposal phases for all the years investigated. It is seen that a bicycle lane has an increasing trend in carbon footprint reduction in later years. The results in Fig. 4 imply that had a bicycle lane been installed since 2015, the city could have reduced a total GHG of more than 1.15 million tons of carbon dioxide equivalent by 2020.

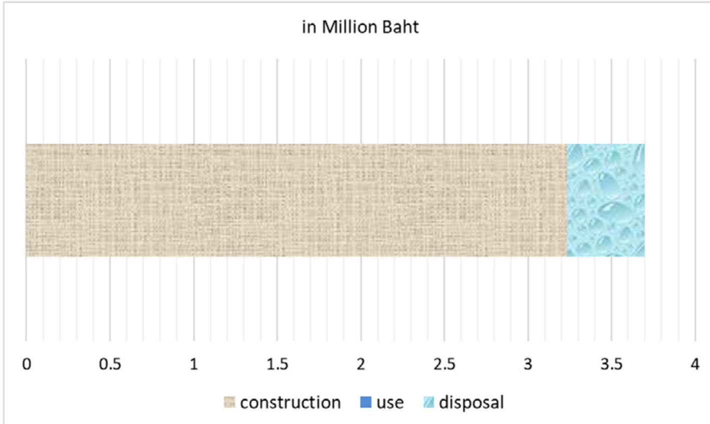

Fig. 5: Life cycle costing in different stages in the year 2020

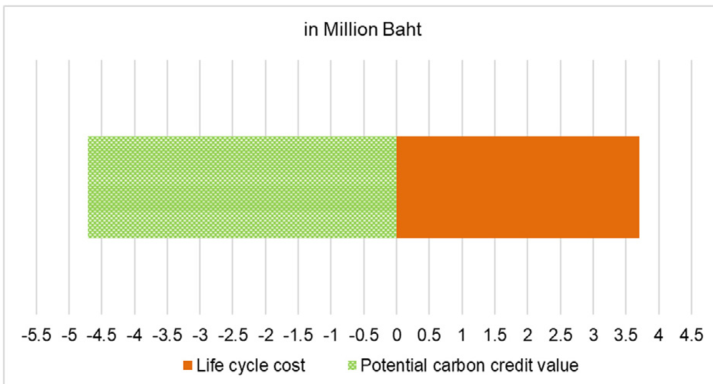

Fig. 6: Potential value of carbon credit compared to life cycle cost in the year 2020

Costing

Costs of each life cycle stage in one year of operating the bicycle lane system in Mahasarakham city are presented in Fig. 5. Based on the functional unit set for this study (use of a bicycle lane for one year), the life cycle cost illustrated in Fig. 4 was calculated yearly. Data for the year 2020 were used in the analysis as it is the most recent data available at the time the study was undertaken. Most of the cost incurred was during the construction stage (about 87%). Therefore, the potential value of carbon credit gained by avoiding GHG emissions was reduced by bicycle lane installation. As shown in Fig. 6, the estimated carbon credit was higher than the one-year life cycle cost of installing the bicycle lane. The potential carbon credit is valued at around 4.7 million baht, while the life cycle cost is approximately 3.7 million baht. The results imply that installing a bicycle lane system could help offset all the life cycle costs by gaining the value of carbon credits of GHG reduction during its life cycle. Moreover, there is also a surplus carbon credit of about 1 million baht remaining after subtracting the total life cycle cost from full carbon credits. This credit signifies that GHG emission could have been avoided in 2020 had a bicycle lane been installed, and 1.27-fold economic benefits would have been garnered. Likewise, Maizlish *et al.* (2017) also proved that cycling helps reduce GHG emissions and provides health co-benefits for cyclists.

Despite the low rate of road users willing to use bicycles even with provision of a bicycle lane, the results still showed positive environmental and economic impacts. A bicycle lane system investment could earn the added ecological and economic benefits if

the municipality promotes bicycles. However, survey results revealed that most road users were unwilling to use bicycles because of safety concerns, weather conditions, and convenience. These issues were also reported in a study about bicycle lane infrastructure in another Thai city (Ratanaburi *et al*., 2021). For sustainable use of the bicycle lane, these issues should be addressed. In addition to global warming, other environmental impacts of a bicycle lane should also be considered. A study conducted by Robinah *et al.* (2022) found that apart from climate change, particulate matter formation is one of the significant issues of road infrastructure equipment. Therefore, it is suggested that further research should investigate other impact categories of a bicycle lane installation.

CONCLUSION

For Thailand to find effective ways to help reduce the GHGs, it will be necessary to target transportation, which is one of the major sectors contributing large amounts of GHGs. Cycling, therefore, is being promoted with the hope of lessening GHGs. While much research has been conducted on the cyclists' aspects, literature examining the bicycle lane infrastructure is limited. Moreover, to prove that a bicycle lane could help reduce GHGs, it is essential to quantify its environmental and economic impacts. This study compares the expected life cycle GHG emissions and costs before and after installing a bicycle lane using LCA and LCC in Mahasarakham, Thailand. The results reveal that using the bicycle lane for one year can help reduce carbon footprint by about 0.2 million tons of carbon dioxide equivalent in 2020. Although only 26% of the vehicle users were willing to use bicycles had a bicycle lane been provided, a modest carbon footprint reduction could still be achieved. Considering the potential of a bicycle lane installation to progressively reduce entire life cycle GHGs in successive years from 2015 to 2020, the bicycle lane was found to have an increased tendency to reduce carbon footprint. This reduction was due to an increasing trend in the number of vehicles every year. Moreover, it is estimated that had a bicycle lane been established in 2015, the city could have reduced the total carbon footprint by more than 1.15 million tons of carbon dioxide equivalent by 2020. The use phase plays a dominant role in reducing environmental impacts. This reduction is the result of decreased fuel usage by vehicles. Considering the various types of automobiles studied, the amount of GHG reduction achieved by pickup trucks was the highest. Pickup trucks play a significant role in carbon emission reduction because they run on diesel fuel, whereas motorcycles and gasoline cars run on gasoline. This reduction is due to the high emission factor of diesel compared to gasoline, thereby resulting in a significant carbon footprint reduction. The reduction in GHG emissions could help offset the total life cycle cost as well. The total carbon credits gained by installing a bicycle lane in Mahasarakham is about 4.7 MB, while the whole life cycle cost in 2020 is approximately 3.7 MB. This credit implies that having a bicycle lane installed in the municipality would provide economic benefits valued 1.27-fold of the total life cycle cost. The findings from this study prove that provision of a bicycle lane reduces GHGs and could be instrumental in the transition to a low-carbon society. In addition, the findings could be used as a guide for other cities to conduct similar studies. Moreover, the results from this study could be used as supporting information to help formulate measures to reduce GHGs in the transportation sector of the city. Based on the results of this study, it is highly recommended that a bicycle lane be constructed to help with GHG reduction in the city. The sooner the bicycle lane is provided, significant GHG reduction could be achieved. In order to promote a sustainable bicycle lane system, safety and convenience issues should be addressed as well. Moreover, it is suggested that other impact categories of a bicycle lane should also be studied in the future.

AUTHOR CONTRIBUTIONS

J. Prasara-A performed the literature review, research design, analyzed and interpreted the data, prepared the manuscript text and manuscript editing. A. Bridhikitti helped in the research design and manuscript editing.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

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ABBREVIATIONS

%	Percent
am	Before noon
BT	Bank of Thailand
C_c	Cost of construction
C_d	Cost of disposal phase
CF	Carbon footprint
CF_a	Carbon footprint after a bicycle lane construction
CF_b	Carbon footprint before a bicycle lane construction
CF_t	Total carbon footprint of the bicycle lane
CH_4	Methane
C_l	Life cycle cost of the bicycle lane
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalent
COP 26	26th session of the Conference of the Parties
C_r	Cost of raw materials
CSS	Center for Sustainable Systems
C_t	Cost of transportation
C_u	Cost of the use phase
EF	Emission factor
EPA	Environmental Protection Agency
Eq.	Equation
Fig.	Figure
GHG	Greenhouse gas
IOS	International Organization for Standardization
ISO	International Organization for Standardization
$kgCO_2eq$	kilogram of carbon dioxide equivalent
km	kilometer
LCA	Life cycle assessment
LCC	Life cycle costing
LCI	Life cycle inventory
LCI_u	LCI data for the use phase of the bicycle lane
LCI_{ua}	LCI data for the use phase of the road after having a bicycle lane installed
LCI_{ub}	LCI data for the use phase of the road before having a bicycle lane installed
MFA	Ministry of Foreign Affairs
N_2O	Nitrous oxide
MB	Million Baht

Mt	Million ton
NSO	National Statistical Office
pm	After noon
SPU	Strategic Planning Unit
t	Ton
TGGMO	Thailand Greenhouse Gas Management Organization

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